Section of Odontology

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The Growth of the Human Face

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INTRODUCTION

THE growth of the human face presents some of the most complex problems of biology, problems which continue to attract the attention of many anatomists and dental research workers. It is not intended in this paper to deal with all the data, experimental and clinical, which has accumulated but rather to attempt the construction of an hypothesis adequate to correlate some of the accumulated information.

GENERAL PRINCIPLES OF SKELETAL AND CRANIAL GROWTH

Growth of the individual elements of the skeleton takes place in one of two ways. (1) The deposition of bone on the surface of cartilage beneath a perichondrium which is becoming a periosteum, followed by the deposition of new bone on the surface of the older bone (surface accretion). In some cases (membrane bones) the earliest bone is laid down in an area of mesodermal condensation in which there is no cartilage. (2) The replacement of growing cartilage by bone (endochondral ossification). In long bones growth in width is produced by surface accretion and growth in length by endochondral ossification at the epiphysis.

There is also a process of internal reconstruction involving the cortical and trabecular structure of individual bones whereby they can continually adapt their internal structure, and to a more limited extent their external form, to the changing requirements of function.

Growth by the replacement of cartilage by bone is an important factor in the growth of the cranial base (which forms the junctional region between the face and cranium), in the condyles of the mandible, and in parts of the facial skeleton related to the nasal capsule. Growth of cartilage continues at some of these sites throughout childhood to the threshold of adult life. It can be stated as a generalization that the growth of cartilage is most active during late fœtal life and early childhood and thereafter becomes of less importance. Co-ordinated bone deposition and resorption is the method whereby the facial and cranial elements increase in size, alter in form and become stronger. This method of growth commences at about the time of birth and becomes of greater significance as development proceeds. In later childhood it is the most important method of growth of the facial skeleton.

GROWTH AT SUTURES

The various bony elements making up the facial skeleton begin to develop close to the primordial facial skeleton comprising the cartilage of the nasal capsule and Meckel's cartilage (Fig. 1). The centres of ossification of some of these bony elements are also related to important nerve trunks (e.g. the mandible, maxillæ and palatine bones). Some develop in membrane just outside the perichondrium of the primordial cartilaginous skeleton; some replace part of the cartilaginous skeleton (ethmoid, inferior turbinate); some in their further growth are associated with masses of secondary cartilage (mandible, maxilla). All of them, however, are at first widely separated from one another and each developing element is enclosed within its own periosteal capsule consisting of an inner

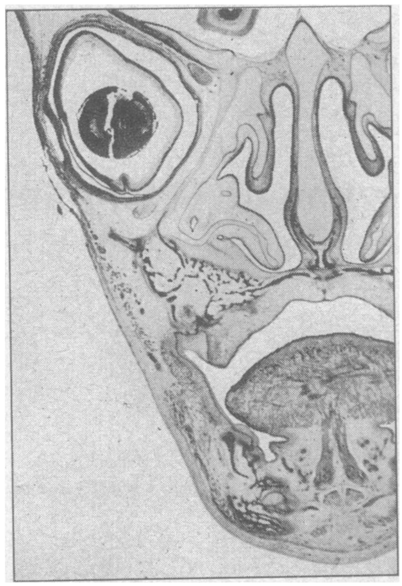

FIG. 1.—Coronal section of the face of a 70 mm. C.R. human fœtus showing Meckel's cartilage, the cartilage of the nasal capsule and the related bones; the mandible, maxilla, zygomatic and vomer.

cellular osteogenetic zone and an outer fibrous membranous part. The periosteal capsules contain at an early stage all the bone-forming cells from which, and from the descendants of which, the bony element is derived. It is unlikely that at a later stage there is any migration of bone-forming cells from outside the periosteal capsule. Therefore the intracapsular osteogenetic cells by their activity and the pattern of their mitotic divisions determine the form of the bony element which is derived from them. They are in all probability the gene-controlled determiners of bone morphology. As they grow, the separate bony elements approach one another until there is a stage in which there is contact between the outer membranous layers of their periosteal capsules, each developing "suture" showing four zones between the actual bony elements (Fig. 2). These are the cellular and membranous regions of the periosteum of each skeletal element. This stage is followed by a union of the membranous layers producing a condition in which there are three zones at each suture. By the union of the adjacent membranous layers at a developing suture, the suture becomes both a site of growth (by surface deposition resulting from the activity of the cellular layers which remain distinct for each bony element) and a site of union. Later, the collagenous fibre bundles become reorientated and run directly from one bony element to the other. The bone-forming cells (osteoblasts) are then greatly reduced in number and are concerned chiefly in the process of internal reconstruction related to the stresses acting upon the bony elements.

The bony elements are not thrust apart by the new bone formed at the sutures as is sometimes taught. Growth takes place at the suture surfaces of the bones by surface deposition as the bony elements are being separated by the growth of cartilage, and by the expansion of organs such as the brain and eyeballs. Sometimes cartilage is present at the sutures themselves as in the mid-palatal suture of such animals as the rat, cat and wallaby. In the growth of the face the cartilage of the nasal capsule, and especially the cartilage of the nasal septum, is an important factor in separating the bony elements which have developed round it and may be regarded as a pacemaker for facial growth. This power of cartilage to separate growing bones at sutures resides in its method of interstitial growth, its turgidity and its ability to resist deforming forces. When bones are no longer being separated at their sutures, growth ceases there except for the overlap of one bony element upon another as along the margin of the squamosal part of the temporal bone. Adjustments to alternating stresses upon the bony elements in contact at a suture line, which produce the zigzag type

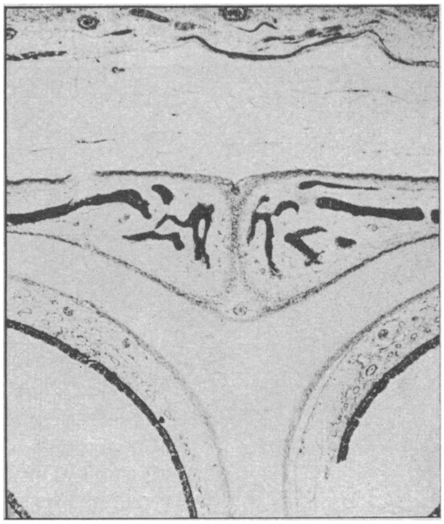

FIG. 2.—Coronal section of a 125 mm. C.R. sheep fœtus showing the suture between the nasal bones with the four primary layers of the sutural tissue. In the upper part of the suture the membranous layers are uniting.

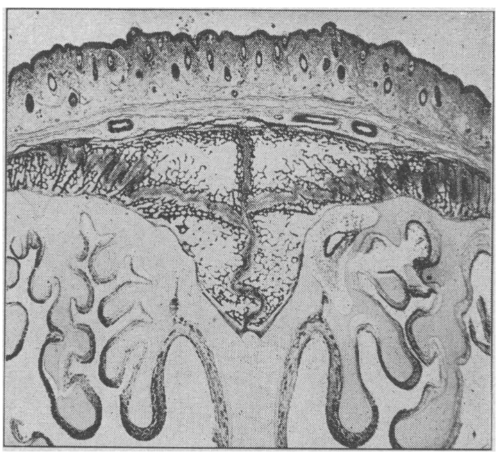

FIG. 3.—Coronal section of a newborn pig showing the zig-zag suture formation at the fronto-nasal region.

of suture (Fig. 3) should be regarded as internal reconstruction rather than true growth. Madder or alizarin, however, would fail to distinguish between the bone deposited in a reconstruction as opposed to a process of expansion.

SITES OF SKELETAL GROWTH IN THE SKULL

The Cranial Base.—This region is of importance because it is the junctional area between the cranial and facial parts of the skull and because it is used, or parts of it are used, in many of the superimposition techniques in the analysis of skull growth. In man, after birth, it consists of four elements between basion and nasion; these are the basi-occipital, the sphenoid (presphenoid and basisphenoid unite just before birth), the cribriform plate region of the ethmoid (mesethmoid), and the frontal. It can be divided into three parts for the purpose of analysing its growth (Fig. 4).

(1) From basion to the anterior margin of the pituitary fossa. This posterior section grows chiefly by the proliferation of cartilage at the spheno-occipital synchondrosis.

(2) From the anterior margin of the pituitary fossa to the foramen cæcum. This intermediate part grows at the spheno-ethmoidal suture which continues outwards on the roof of each orbital cavity as the spheno-frontal suture.

(3) From the foramen cæcum to nasion. This anterior segment grows by deposition on the anterior surface of the frontal bone and is related to the degree of development of the frontal air sinuses.

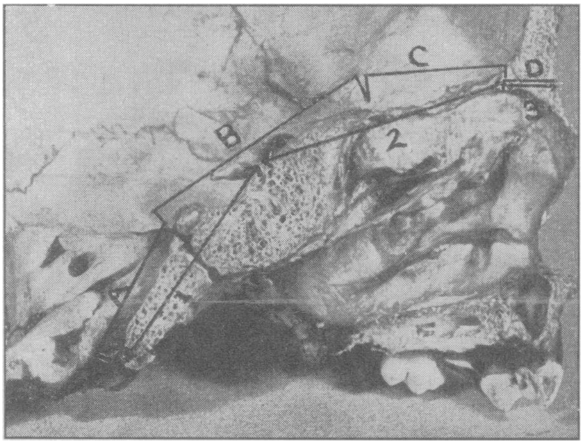

FIG. 4.—Cranial base of a child of 4 years of age to show its form and structure. A, basi-occipital. B, body of sphenoid. C, cribriform plate of ethmoid. D, frontal. 1, 2, 3 are the three parts used in growth analysis.

After the seventh year, growth is completed in the middle segment: that is, there is little if any further growth at the spheno-ethmoidal and spheno-frontal sutures (*see also* de Coster, 1951). Growth continues at the basi-occipital synchondrosis and at the surface of the frontal bone until the end of the second decade. Hence, while growth of the cranial base continues throughout childhood and adolescence it does not occur in all its parts to the same extent.

The coronal suture system.—Growth of the cranial vault in the antero-posterior direction involves two suture systems separating three cranial regions (Fig. 5). These are (1) the lambdoidal suture

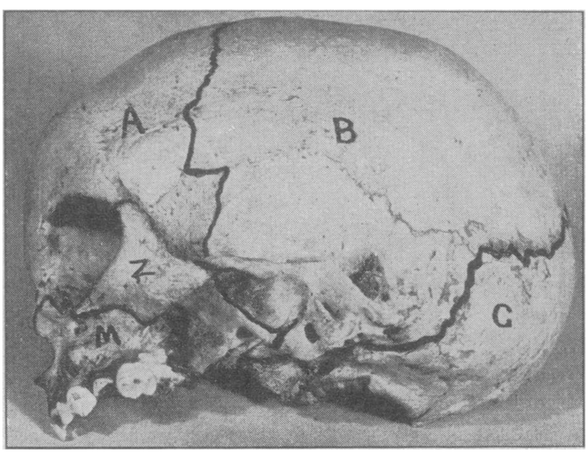

FIG. 5—Skull of a child of 4 years of age showing the cranial segments and the maxillary sutures. A, anterior cranial segment. B, middle cranial segment. C, posterior cranial segment. Z, zygomatic bone. M, maxilla.

system separating the occipital bone behind from the parietal and temporal bones in front. The occipital bone forms the posterior cranial segment and the parietal and temporal bones the middle cranial segment. (2) The coronal suture system above the pterion separates the frontal from the parietal bones. Below the pterion it divides into two parts, an anterior, running between the frontal and great wing of the sphenoid, and a posterior running between the great wing of the sphenoid and the temporal. The posterior limb is the more important and with the supra-pterion part of the coronal suture system separates the frontal and sphenoid bones in front from the parietal and temporal bones behind. The frontal and sphenoid bones make up the anterior cranial segment and except for the zygomatic arches carry the skeleton of the upper face. At the cranial base the lambdoidal suture system and the posterior limb of the coronal suture system meet in relation to the spheno-occipital synchondrosis. This synchondrosis is therefore an important element in the growth of both these suture systems. At this synchondrosis the anterior (sphenoid) and posterior (occipital) cranial segments meet one another. The middle cranial segment does not reach to the middle line of the cranial base.

The basi-occipital synchondrosis lies in the roof of the nasopharynx and the growth of its cartilage elongates the cranial base. It also projects the whole upper facial skeleton forward from the vertebral column; increases the antero-posterior extent of the nasopharynx, and makes room for the growth of the muscles of mastication and for the growth of the mandibular ramus. Growth at the synchondrosis will also increase the size of the cranial cavity. In later childhood this increase in size is probably associated with thickening of the skull by surface deposition on the interior of the bones of the vault, rather than any growth in brain size.

Examination of a skull shows that the anterior limb of the coronal suture system separates the zygomatic bone and great wing of the sphenoid bone within each orbital cavity and at the cranial base it includes the suture between the small wing of the sphenoid and the frontal bone, and between the sphenoid and ethmoidal bones. That is, the anterior limb of the coronal suture separates the sphenoid bone and its various processes from the ethmoid, frontal, zygomatic and palatine bones. It is an important site of cranial, orbital and facial growth during late fœtal life and up to about the seventh year.

The nasal septum.—The nasal septum at birth consists of hyaline cartilage which is continuous above and behind with the cartilage of the cranial base. This region of the cartilaginous cranial base has been largely replaced by the body of the sphenoid bone. Below, the lower free margin of the septum is embraced for the greater part of its extent by the developing bilaminar vomer which interposes itself between the septal cartilage and the hard palate. In front, however, the cartilage reaches the maxilla (its premaxillary part) above and behind the nasal spine of the nasal aperture. The cartilage is not directly united to the vomer but lies along the vomerine groove and is separated from the bone by perichondrium and a mass of loose fatty tissue. It is more firmly united by fibrous tissue to the premaxillary region of the maxilla in front of the vomer. At the roof of the nasal cavity the cartilage of the septum is continuous with the cartilage of the side walls of the nasal capsule behind and in front of the opening for the olfactory nerves (cribriform plate region). The greater part of the cartilage of the lateral wall of the capsule is replaced by the lateral masses of the ethmoid bones in which the ethmoidal air cells develop, and by the inferior turbinate bones.

Soon after birth a centre of ossification appears in the upper back part of the cartilaginous nasal septum. This is the centre for the mesethmoid which is an element of the cranial base. Ossification from this centre extends downwards as the perpendicular plate of the ethmoid, and upwards into the crista galli to which the falx cerebri is attached. Between 3 and 5 years of age ossification extends across the cribriform plate region to unite the facial (lateral mass) and cranial (mesethmoid) elements of the ethmoid. About a year later the perpendicular plate unites in bony union with the vomer at the back of the nasal septum. After the 7th year there is no further growth of the cribriform plate (intermediate segment of the cranial base) and two of the facial bones, the lateral mass of the ethmoid and the vomer, are now united to the most anterior element of the cranial base (mesethmoid). In many animals such as the sheep, pig, and elephant, the mesethmoid is absent and the perpendicular plate of the ethmoid is formed by a forward extension of the sphenoid (presphenoid).

Growth of the cartilage of the nasal septum will thrust all the facial bones (except the mandible) downwards and forwards from the cranial base and separate them from one another (Scott, 1953). The union of the parts of the ethmoid with one another and with the vomer stabilizes the craniofacial union. Growth of the septal cartilage could still, in theory, separate the maxillary and palatine bones from the ethmoid and vomer and thus produce the deepening of the nasal cavities which occurs after the seventh year.

The maxillary sutures.—The most important sutures related to the maxilla from the point of view of its growth are those between the maxilla and the frontal, zygomatic, ethmoid and palatine bones. It has been pointed out (Weinmann and Sicher, 1947) that these sutures are, in general, so disposed that growth at them would thrust the maxilla downward and forward (Fig. 5). The form of the frontomaxillary suture is, in fact, so disposed, but a careful examination of the zygomatic-maxillary suture shows that growth at this suture would thrust the zygomatic bone outwards or the maxilla inwards, while the suture between the ascending process of the palatine bone and the maxilla in the lateral wall of the nasal cavity is so complex that growth at the suture could have no direct effect in moving the maxilla. These sutures are so arranged, however, especially in early childhood, as to permit the maxilla to be thrust downward and forward between the adjacent bones by the growth of the septal cartilage and the contents of the orbital cavities.

By the seventh year growth of the orbital cavities is almost complete and any further thrusting downwards of the maxilla would continue to increase the height of each orbital cavity. This could be compensated for by deposition of bone on the orbital surface of the maxilla which would, however, be associated with an increase in height of the maxillary antrum above the level of its opening into the middle meatus. It would also convert the whole of the infra-orbital groove on the orbital floor into a canal. These changes do not, however, take place so that the deepening of the nasal cavities which occurs after the 7th year must be produced by resorption on the floor of each cavity and deposition of new bone on the oral surface of the hard palate. That this occurs is shown by the deepening of the inferior meatus and the development of the maxillary crest at the base of the nasal septum.

The sutures of the zygomatic bone.—Separation of the zygomatic and temporal bones at the suture of the zygomatic arch is produced by growth of the cranial base at the spheno-occipital synchondrosis. It is therefore part of the coronal suture system. The suture between the maxilla and zygomatic bones has already been described. It is part of the septal suture system in that the bones forming it are separated by growth of the cartilage of the nasal septum. It is also, however, with the suture between the zygomatic bone and great wing of the sphenoid, concerned in the growth in width of the face and especially in the growth in width of the orbital cavity. The zygomatico-frontal suture is related to the growth in height of the orbital cavity.

The zygomatic bone, therefore, is related in its growth to the eyeballs, septal cartilage and the cartilage of the cranial base. The cartilage of the cranial base is a site of growth up till the end of the second decade; the septal cartilage and eyeball have completed their growth before the end of the first decade.

It should be remembered that sutures are places where the bony elements of the skull are united to one another and the growth of such organs as brain and eyeball and of cartilage, unless there is actual bony union, will involve more than one bony element and more than one suture system. For example, up to the 7th year the septal cartilage thrusts the maxilla downwards and forwards, but because this bone is united to the zygomatic and palatine bones by sutures these bones will also be drawn downwards and forwards. Growth of the basi-occipital synchondrosis will separate the temporal and zygomatic elements of the zygomatic arch and will also tend to draw the zygomatic bone backwards with the temporal bone. It is the total result of such growth tensions which determines the amount of growth at the various sutures.

The zygomatic bone is an important element in the facial buttress system whereby the forces of mastication are transmitted from the teeth to the cranial base. With the development of the dentition there is an increase in these forces and correlated with this a reconstruction of the bony architecture involving the sutural regions. As a result madder feeding or alizarin red will indicate bone formation, which need not, however, indicate expansive bone growth.

The lower jaw.—Growth of the mandible has received much more attention than growth of the other bones of the face. The characteristic feature is the importance of the secondary cartilage of the head of the condyle. Growth in height of the body is mainly by deposition along the subgingival alveolar border, and growth in width of the ramus is entirely by growth at its posterior edge. It is uncertain how much growth takes place along the outer surface of the body in the human mandible. Studies in comparative anatomy indicate that in many animals growth in length of the mandible is the result of surface deposition in front as well as at the posterior borders of the rami. Recent work shows that surface deposition at the front of the mandible is a factor of some importance in the monkey (*Rhesus macaque*) (Baume, 1953). Growth in length of the mandible is closely correlated with growth in width of the ramus. If all or most of the growth takes place at the back of the ramus there must be an extensive resorption of bone at the front of the ramus to uncover the developing permanent molars. It is usually held that there is some resorption of bone in this position, but there is probably less than the amount needed to uncover the three permanent molars, as there is a good deal of evidence that the teeth migrate forwards from their developmental position in the alveolar bulb. The presence of osteoclasts along the anterior edge of the coronoid process may be associated with adjustment of the attachment of the temporal muscle in a manner similar to the changes occurring in relation to the attachment of the lateral pterygoid (Symons, 1953).

It is usually stated that growth of the condylar cartilages thrusts the mandible downward and forward from the glenoid fossæ. It may be more accurate to say that growth of the cartilage permits of growth of the condyle upwards and backwards so as to maintain contact at the temporo-mandibular joint as the mandible is carried downwards and forwards by the growth of the upper facial skeleton. The head of the condyle is very similar to the two ends of the clavicle and it is probably more accurate to state that growth of the clavicle takes place so as to maintain contact with the sternum at one end and the scapula at the other, rather than to say that growth of the clavicle thrusts the scapula away from the sternum.

THE RATE AND PATTERN OF FACIAL GROWTH

Table I gives the measurements of some facial and cranial dimensions at birth, 3, 7, 10 years and in the adult. The measurements are mean values for male children and do not take account of the variation about the mean for each age group. The data, however, does show that at 7 years cranial length, cranial width and orbital height are nearly 95% of the adult dimension, while facial height is only 80%. At 10 years the cranial and orbital measurements have reached or exceeded 95% of the adult size, while the facial measurements have reached to about 85% of the adult size. At 10 years the height of the maxillary antrum is only 55% of the adult size. Growth in height of the antrum is closely related to growth of the maxillary alveolar process.

[Throughout this paper measurements are expressed in millilitres and millimetres.]

TABLE I.—CRANIAL AND FACIAL MEASUREMENTS (MALE) AT BIRTH, 3 YEARS, 7 YEARS, 10 YEARS, AND IN THE ADULT

(data from various sources)

Measurement	Birth	3 years	7 years	10 years	Adult
Cranial capacity	350 (24%)	1,225 (82%)	1,350 (90%)	1,425 (95%)	1,500
Cranial length	120 (60%)	175 (88%)	185 (93%)	190 (95%)	200
Cranial width	95 (63%)	135 (90%)	142 (95%)	145 (97%)	150
Orbital height	18 (55%)	26 (79%)	31 (94%)	32 (97%)	33
Cranial base	56 (56%)	76 (76%)	85 (85%)	90 (90%)	100
Bizygomatic width	85 (61%)	112 (80%)	116 (83%)	122 (87%)	140
Upper face height	30 (43%)	50 (70%)	56 (80%)	60 (86%)	70
Total face height	50 (40%)	85 (65%)	100 (80%)	105 (84%)	125
Height of maxillary antrum	5 (18%)	12 (36%)	17 (51%)	18 (55%)	33

Figures in brackets give the percentage of the adult dimension.

It is interesting to note that in its growth the cranial base (basion to nasion) is intermediate between the cranial and facial dimensions. Growth of the middle segment of the cranial base, however, (pituitary fossa to foramen cæcum) is completed by the 7th year.

The well-known difference in the growth rate of the cranial and facial parts of the skull can be demonstrated by using cranial and facial modules. The cranial module is here taken as the sum of cranial length and cranial width divided by 2, and the facial module as the sum of total facial height and bizygomatic width divided by 2.

Table II gives the modules at different ages (data from Low, 1952 and Flemming, 1933).

TABLE II.—CRANIAL AND FACIAL MODULES (MALE)

	Cranial module	Facial module
3 days	108	69
1 year	145 (37)	91 (22)
3 years	156 (11)	100 (9)
5 years	159 (3)	105 (5)
8 years	162 (3)	107 (2)
10 years	165 (3)	109 (2)
12 years	166 (1)	112 (3)
15 years	171 (5)	121 (9)
17 years	173 (2)	126 (5)
Adult	175 (2)	133 (7)

Figures in brackets show increase over previous measurement.

It will be seen that while the cranial module increases by a little over 50% from 3 days to adult life, the facial module increases by a little less than 100%. Note that in both cranium and face the greatest amount of growth takes place in the first year; that the period of rapid post-natal growth ceases in the cranium at the end of 3 years, and in the face at the end of 5 years; that there is a slight increase in the rate of cranial growth during adolescence and a greater increase in the rate of facial growth.

From what has been stated previously in this paper it can be said as a useful generalization that the cranial type of growth depends upon expansion of the brain and orbital contents, while the facial type of growth derives its early impetus from the growth of cartilage, but is largely dependent, especially at the later stage, on surface deposition. Surface deposition is also responsible for the less marked increase in cranial dimensions which occurs in adolescence.

It is sometimes stated that growth in any dimension of the face or cranium is continuous and regular in nature. This belief is the result of using the mean values of large numbers of measurements within each age group. Analysis of the growth of individuals, however, shows that growth proceeds in an irregular and jerky manner, and that the pattern of growth varies to a considerable extent in each individual.

Table III gives the figures of total face height of six boys from Low's measurements (Low, 1952). Note the difference between the growth of individual cases and the type of growth suggested by the mean values for the series.

TABLE III

Case No.	3 days	1 year	2 years	3 years	4 years	5 years	Total increase
1	47	76 (29)	80 (4)	88 (8)	88 (0)	95 (7)	48
2	55	67 (12)	80 (13)	92 (12)	98 (6)	102 (4)	47
3	50	70 (20)	78 (8)	83 (5)	92 (9)	93 (1)	43
4	51	68 (17)	76 (8)	87 (9)	93 (6)	100 (7)	49
5	53	82 (29)	82 (0)	90 (8)	90 (0)	100 (10)	47
6	57	82 (25)	88 (6)	92 (4)	94 (2)	94 (0)	37
Mean	50·6	72·2 (21·6)	78·7 (6·5)	84·3 (5·6)	88·5 (4·2)	92·3 (3·8)	42·7

The figures in brackets show the increase over the previous measurement.

There is also a change in the shape of both the cranium and face during childhood. The cranial index (breadth × 100/length) usually decreases slightly, while the facial index (height × 100/breadth) increases to a considerable extent; that is, the length of the cranium and the height of the face increase relative to their width. This is especially true in the case of the face.

More important information on head form and face form would be obtained if, in any given series, we could establish a means of estimating the degree of correlation between them. I have found it useful to classify the cranial and facial skeleton in each individual into one of the following classes: Long wide (Group A), Long narrow (Group B), Long moderate (Group C), Short wide (Group D), Short narrow (Group E), Short moderate (Group F), Moderate wide (Group G), Moderate narrow (Group H), Moderate (Group M), that is nine classes in all. The relationship between cranium and face can be expressed as being one of three degrees of harmony.

(1) Complete harmony, e.g. long wide cranium, with long wide face.
(2) Partial harmony, e.g. long wide cranium with short wide face.
(3) Disharmony, e.g. long wide cranium and short narrow face.

Table IV shows the distribution of cranial and facial types and the degree of harmony among 115 males from the town of Ballymoney in Northern Ireland.

TABLE IV.—GROUPS WITH % DISTRIBUTION

	A	B	C	D	E	F	G	H	M
Cranium	30	1	8	9	4	10	17	4	16
Face	29	6	7	15	4	6	15	4	14

Degree 1 harmony 26%
Degree 2 „ 42%
Degree 3 „ 32%

It will be noticed that although in both the cranium and face the long wide (Group A) type is the most common and that the number in each group is much the same for cranium and face, there is, in fact, no strict correlation between facial and cranial form.

In the facial skeleton itself various degrees of harmony or disharmony may exist between the form of its different parts such as the orbital cavities, nasal cavity and palatal region. It would seem that the forms of these various parts of the skull are under the control of independent genetic factors. Growth in facial height involves growth of the orbital cavities, nasal cavity and mouth region. Growth in facial width (bizygomatic) involves growth of the nasal cavity, orbital cavities and the flare of the zygomatic arches. Each of these regions has a different pattern of growth and the same total dimension in two individuals may have different contributions from each region.

Much work remains to be done on the growth of these individual parts of the facial skeleton and their correlation. Table V, which gives some measurements of two microcephalic skulls, illustrates the complexity of the problem.

TABLE V.—DIMENSIONS OF 2 MICROCEPHALIC SKULLS
(*Queen's University Anatomy Department*)

	1	2	Range of 300 Scottish male skulls
Cranial capacity	455	695	1,170–1,930
Cranial length	140	153	171–204
Cranial width..	103	108	128–152
Cranial base	94	92	86–112
Upper facial height	68	62	57–83
Orbital height	32	34	28–39
Bizygomatic width	106	105	114–143
Palatal width (internal) ..	40	30	29–44

It will be seen that the cranial and bizygomatic measurements of both skulls are below the normal range, that upper facial height, orbital height and the cranial base length are within the normal range and that the palate width is close to the upper limit of the normal range in one skull and close to the lower limit in the other. The second skull, however, is edentulous.

Table VI gives the measurements of two acromegalic skulls (Geddes, 1911) and two hydrocephalic skulls (Queen's University, Anatomy Department).

TABLE VI.—DIMENSIONS OF TWO ACROMEGALIC AND TWO HYDROCEPHALIC SKULLS

	Acromegalic		Hydrocephalic		Range of 300 Scottish male skulls
	1	2	3	4	
Cranial capacity	—	—	2,660	2,980	1,170–1,930
Cranial length	189	201	218	214	171–204
Cranial width	146	148	176	181	128–152
Cranial base	126	106	98	112	86–112
Upper facial height	98	82	69	76	57–83
Orbital height	40	36	31	37	28–39
Bizygomatic width	133	150	—	140	114–143
Palatal width (external)	63	70	—	—	49–70
Palatal width (internal)	—	—	38	43	29–44

Note.—No. 1 is a female.

In both the acromegalic skulls (Nos. 1 and 2) the cranial measurements are within the range of normal. In skull 1 the length of the cranial base, the upper facial height, and the orbital height are above the normal range. In skull 2, however, the cranial base length is within the normal range, bizygomatic width is above the normal, while the upper facial height and palate width are high up within the normal range. In the hydrocephalic skulls (Nos. 3 and 4) only cranial capacity, cranial length and cranial width are outside the normal range.

The measurements of these abnormal skulls show the independence of different regions of the skull and also the powers of compensatory growth. In the first microcephalic skull the failure of growth of the cranium has not affected growth of the palatal region. In the first acromegalic skull the great growth in facial height has not affected palatal width.

Recent work by Symons (1951) and Dixon (1953) on the mandible and maxilla indicates that these bones are built up of quite distinct developmental parts. These are the neural, alveolar, ramal and muscular processes in the mandible, and the neural, alveolar, zygomatic and palatal processes in the maxilla. The neural elements are related to the mandibular and infraorbital nerves, and the ramal element of the mandible corresponds to the zygomatic process of the maxilla in that both depend upon a mass of secondary cartilage for their growth. The muscular processes of the mandible are the angle and coronoid processes and are the only parts which depend on muscular function for their development. Moore and Hughes (1942), and Hughes (1942) concluded that multiple genetic factors were concerned with the development of the ramus, body, angle, alveoli and teeth in the mandible, and teeth, alveoli and body of the maxilla in the upper jaw. The independent origin of these parts increases the probability of such a gene-regulated developmental mechanism.

DISCUSSION

The evidence brought forward in this paper, although incomplete, indicates that the growth of the human face after birth falls into two distinct phases:

(1) From birth to about the 7th year of age.

(2) After the 7th year.

During the first phase growth is, to a considerable extent, regulated by the cartilage of the nasal septum, cranial base and mandibular condyle. Growth takes place at the sutures as these are separated by the growth of the cartilage of the nasal septum and of the orbital contents. The orbital cavity is increasing in size and the Frankfort plane is not at this time a staple landmark. Growth is active in both the cranial and facial regions of the skull and at the junctional area between them (the cranial base). All parts of the cranial base are increasing in size. During this period the deciduous dentition is in use and the facial muscles are relatively more active and more fully developed than the muscles of mastication.

After the 7th year, that is during the second phase, growth of the nasal septum ceases and also growth at the facial sutures. Growth of the contents of the cranial and orbital cavities is almost complete as is the middle segment of the cranial base (pituitary fossa to foramen cæcum). The Frankfort plane becomes stabilized and with the completion of sutural growth the cranio-facial union becomes consolidated to meet the mechanical stresses associated with the use of the developing permanent dentition. In this phase growth of the facial skeleton is predominantly a matter of surface deposition and internal reconstruction. The cartilages of the mandibular condyle and of the cranial base (spheno-occipital synchondrosis) continue, however, to function as important growth sites in thrusting the facial skeleton forwards from the vertebral column. The muscles of mastication reach their full development at the end of this period with the completion of the permanent dentition.

SUMMARY

(1) The cartilage of the cranial base, nasal capsule and Meckel's cartilage act as pace-makers for the early growth of the facial skeleton.

(2) The middle segment of the cranial base is complete by the 7th year and is the most stable region of the skull after that time.

(3) Growth at the facial sutures is secondary to a process of separation at the sutures which is produced by proliferation of cartilage and expansion of such organs as the brain and eyeballs.

(4) Growth of the face is intermittent in nature and differs in its pattern for different regions.

(5) The relationship in form between the facial and cranial regions of the skull may be harmonious or disharmonious.

(6) Analysis of skulls showing abnormal growth illustrates the developmental independence of various regions of the skull.

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Comments on "The Solution of the Piltdown Problem"

By ALVAN T. MARSTON, F.D.S.

ON November 21, 1953, the British Museum (Natural History) published the *Bulletin*, Geology, Vol. 2, No. 3. *The Times* of the same day published an article from "Our Museums Correspondent' on the "Piltdown Man Forgery—Jaw and Tooth of Modern Ape—Elaborate Hoax". On the same date the B.B.C. further publicized the matter in its news bulletins, and the Keeper of Geology of the British Museum (Natural History) also broadcast on the subject. There can be little doubt that it was a pre-planned and synchronized effort.

By 1952 I had succeeded in getting published fresh evidence relating to the Piltdown problem: "The relative ages of the Swanscombe and Piltdown skulls, with special reference to the Fluorine Estimation Test", in 1950*a*; "Reasons why the Piltdown canine tooth and mandible could not belong to Piltdown Man", which was submitted in 1950 but not published until 1952, although its salient features had been published in the Proceedings of the Geological Society of London for December 14, 1949 (Marston, 1950*b*), and finally my note on the "Human Mandibular Lacteon Constant" (*mihi*) had been published in *Man* (Marston, 1952*c*). The effect of these was to render the British Museum's attitude in presenting *Eoanthropus dawsoni* to the public as a "missing-link", untenable.

Nevertheless *Eoanthropus dawsoni* was allowed to figure in the Dome of Discovery, South Bank Exhibition in 1951, and in a somewhat similar exhibit in the Natural History Museum in 1952 and 1953, to explain the theory of human evolution from an ancestral ape, perhaps the Miocene *Proconsul.* This showed clearly a refusal on the part of the British Museum to face up to the facts of the evidence which I had published.